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(54) **Method of optimizing reductant addition to an SCR catalyst coupled to an internal combustion engine**

(57) A method for controlling reductant injection into a catalyst coupled to an internal combustion engine, comprises determining NO_x conversion and ammonia concentration and if the post-catalyst ammonia concentration is less than an allowable fraction and level, the

amount of reductant is increased as long as there is an increase in NO_x conversion and the post-catalyst ammonia concentration is kept below the allowable fraction and level. Otherwise, the amount of reductant injected is decreased until the post-catalyst ammonia concentration is below the allowable fraction and level.

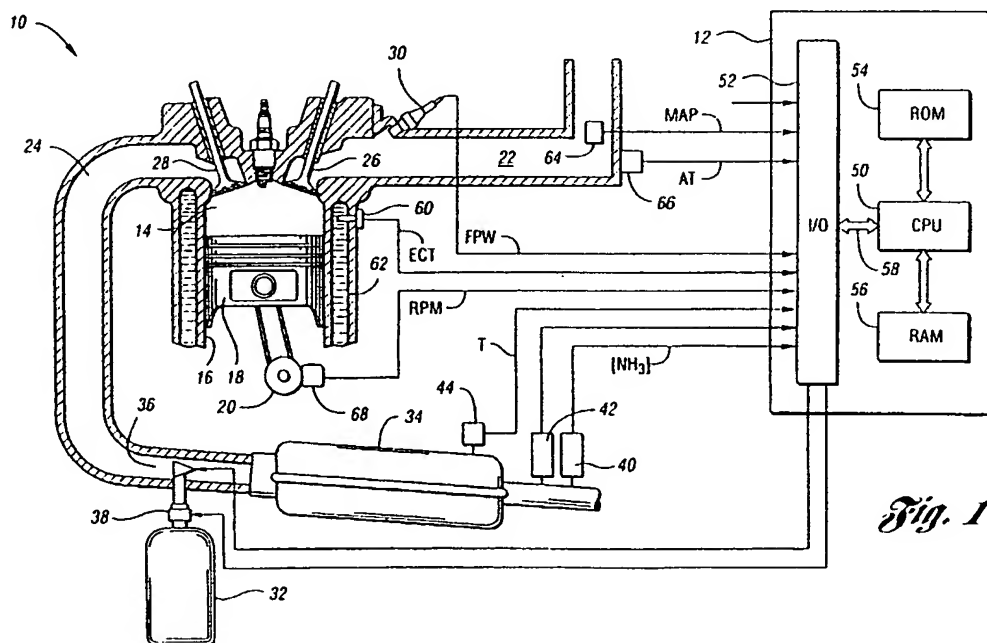


Fig. 1

Description

[0001] The invention relates to controlling ammonia injection upstream of a selective reduction catalyst coupled to an internal combustion engine.

[0002] In order to meet emission regulations, selective catalytic reduction systems using externally added reducing agents may be used. In such a system, regulated emissions, such as nitrogen oxides, or NO_x , can be reduced in an oxygen-rich environment to nitrogen and water over a catalyst when a reducing agent, such as ammonia, is added. In addition to controlling nitrogen oxide emissions, the amount of excess ammonia, or ammonia slip, must be managed. Ammonia slip is experienced when ammonia in excess of that used to reduce the nitrogen oxides passes through the catalyst unaffected and exits the catalyst (as ammonia slip).

[0003] One method for regulating ammonia slip is to use an ammonia sensor located downstream of the catalyst. The detected ammonia concentration is compared with a fixed upper threshold value. This comparison generates a correction signal that is used to control the metering of ammonia upstream of the catalyst. Allegedly, by regulating actual ammonia slip to the upper threshold value, a certain nitrogen oxide reduction is obtained. Such a system is disclosed in U.S. Patent 5,369,956.

[0004] Another method for regulating nitrogen oxide emissions and ammonia slip is to use an after-catalyst NO_x sensor to detect nitrogen oxide concentration. Control of NO_x emissions is achieved by varying reductant injection until the level or quantity of nitrogen oxides as measured by the sensor falls within an acceptable limit. The amount of reductant injected to keep NO_x emissions within the acceptable limit needs to be balanced with an ammonia slip limit. This can be measured and controlled by an after-catalyst ammonia sensor. Such a system is disclosed in U.S. Patent 5,233,934. Alternatively, ammonia slip can be calculated and controlled using an algorithm. Such a system is disclosed in U.S. Patent 4,751,054.

[0005] In general, as maximum NO_x conversion is approached with increasing ammonia addition (i.e., increasing NH_3/NO_x molar ratio), ammonia starts to slip. After maximum NO_x conversion is attained, ammonia slip increases more rapidly with increasing NH_3/NO_x . For example, if ammonia slip is regulated to a constant concentration value, an ammonia setting high enough for sufficient NO_x conversion at high NO_x feed gas levels is likely excessive for low NO_x feed gas levels, thereby wasting ammonia. Conversely, a setting at minimum detectable ammonia concentration is likely insufficient to provide high NO_x conversion at high NO_x feed gas levels. Further, intermediate settings may still be insufficient to provide high enough NO_x conversion at high NO_x feed gas levels. Thus, prior approaches cannot achieve high NO_x conversion with minimal ammonia slip, particularly for vehicle engines where NO_x concen-

tration levels varies widely and quickly. In other words, because a catalyst experiences widely varying levels of engine NO_x , controlling to an ammonia slip concentration results in widely varying, and less than optimum, NO_x conversion efficiency.

[0006] In accordance with the present invention, a method for controlling reductant injection into a catalyst coupled to an internal combustion engine is dependant on whether the post-catalyst ammonia concentration is less than an allowable fraction and level. If so, the amount of reductant is increased as long as there is an increase in NO_x conversion and the post-catalyst ammonia concentration is kept below the allowable fraction and level. Otherwise, the amount of reductant injected is decreased until the post-catalyst ammonia concentration is below the allowable fraction and level.

[0007] The invention will now be described further, by way of example, with reference to the accompanying drawings, in which:

Figure 1 is a schematic block diagram illustrating the present invention; and

Figure 2 is a flowchart of a method embodying the present invention.

[0008] Referring now to the drawing and initially to Figure 1, internal combustion engine 10, comprising a plurality of cylinders, one cylinder of which is shown in Figure 1, is controlled by electronic engine controller 12. Engine 10 includes combustion chamber 14 and cylinder walls 16 with piston 18 positioned therein and connected to crankshaft 20. Combustion chamber 14 is shown communicating with intake manifold 22 and exhaust manifold 24 via respective intake valve 26 and exhaust valve 28. Intake manifold 22 is also shown having fuel injector 30 coupled thereto for delivering liquid fuel in proportion to the pulse width of signal FPW from controller 12. Both fuel quantity, controlled by signal FPW and injection timing are adjustable. Fuel is delivered to fuel injector 30 by a conventional fuel system (not shown) including a fuel tank, fuel pump, and fuel rail (not shown). Alternatively, the engine may be configured such that the fuel is injected directly into the cylinder of the engine, which is known to those skilled in the art as a direct injection engine.

[0009] Reducing agent, for example, ammonia, is stored in storage vessel 32 coupled to exhaust manifold 24 upstream of a selective reduction catalyst 34. Control valve 36 controls the quantity of reducing agent delivered to the exhaust gases entering catalyst 34. Pump 38 pressurizes the reducing agent supplied to control valve 36. Both pump 38 and control valve 36 are controlled by controller 12.

[0010] Ammonia sensor 40 and NO_x sensor 42 are shown coupled to exhaust manifold 24 downstream of catalyst 34. Temperature sensor 44 coupled to catalyst 34 provides an indication of the temperature (T) of catalyst 34. Alternatively, catalyst temperature (T) could be

estimated using methods known to those skilled in the art and suggested by this disclosure. Ammonia sensor 40 provides an indication of ammonia concentration [NH₃] to controller 12 for determining a control signal sent to control valve 36 as described later herein with particular reference to Figure 2.

[0011] NO_x sensor 42 provides an indication of NO_x concentration which is used with the expected engine out NO_x level to indicate the level of NO_x conversion to controller 12 for determining a control signal sent to control valve 36 as described later herein with particular reference to Figure 2. The engine out NO_x level may be predicted using methods known to those skilled in the art and suggested by this disclosure.

[0012] Controller 12 is shown in Figure 1 as a conventional microcomputer including: microprocessor unit 50, input/output ports 52, read-only memory 54, random access memory 56, and a conventional data bus 58. Controller 12 is shown receiving various signals from sensors coupled to engine 10, in addition to those signals previously discussed, including: engine coolant temperature (ECT) from temperature sensor 60 coupled to cooling sleeve 62; a measurement of manifold pressure (MAP) from pressure sensor 64 coupled to intake manifold 22; a measurement (AT) of manifold temperature from temperature sensor 66; an engine speed signal (RPM) from engine speed sensor 68 coupled to crankshaft 20.

[0013] Referring now to Figure 2, a flowchart of the method of the present invention is shown. The variables discussed hereinafter are:

NC = NO_x conversion
 NC_i = initial value of NC
 NC_n = next value of NC
 NC_p = previous value of NC
 R = NH₃/NO_x molar ratio
 r = value by which to increase or decrease R
 Fr = fraction of reductant fed into the catalyst that is measured after the catalyst as ammonia
 Fr_{AL} = highest allowable Fr
 [NH₃] = ammonia concentration level
 AL = allowable level of ammonia post-catalyst

[0014] The initial NO_x conversion NC_i and ammonia concentration [NH₃] are measured at block 80. If the initial ammonia concentration is less than an allowable level of post-catalyst ammonia, AL, and the fraction of reductant fed into the catalyst that is measured after the catalyst as ammonia, Fr, is less than an allowable fraction Fr_{AL}, all as determined in block 82, then as indicated in block 84, the amount of reductant is increased to achieve a mole ratio $R = R + r$, where r is a predetermined increase in the ratio. As long as the next value of NO_x conversion NC_n is greater than the previous value of NO_x conversion NC_p as determined in decision block 86, and the ammonia concentration is kept below the allowable fraction and level as indicated in decision

block 88, the amount of reductant is increased by adding r to R. If the ammonia concentration is above the allowable fraction or above the allowable level, as determined in decision block 82 or decision block 88, the amount of reductant injected is decreased as indicated in block 90 until the ammonia concentration is below the allowable fraction and level as determined by decision block 92.

[0015] Molar ratio (R) is the ratio of the number of moles of ammonia to the number of moles of nitrogen oxide in engine out exhaust gas. The moles of nitrogen oxide in engine out exhaust gas is calculated based on experimentally determined relationships between nitrogen oxide quantity and engine operating conditions known to those skilled in the art to be indicative of estimated engine out nitrogen oxide quantity (NO_x^{est}) such as, for example, engine speed, manifold pressure (MAP), intake air temperature (AT), injection timing, injection quantity (FPW), and engine coolant temperature (ECT).

Claims

1. A method for controlling reductant injection into a catalyst coupled to an internal combustion engine, the method comprising the steps of:

increasing the amount of reductant injected if the post-catalyst ammonia concentration is less than an allowable level and the ammonia slip fraction is less than an allowable fraction, else
 decreasing the amount of reductant injected until the ammonia concentration is below the allowable fraction and level.

2. A method as claimed in claim 1, comprising the further steps of:

determining an initial NO_x conversion NC_i and ammonia concentration [NH₃]; and
 decreasing the amount of reductant injected if the initial ammonia concentration is above the allowable fraction or above the allowable level.

3. A method as claimed in Claim 1 or 2, wherein the reductant is an ammonia generating material.

4. A method as claimed in Claim 1, 2, or 3, wherein the amount of the increase or decrease of injected reductant is sufficient to respectively increase or decrease the ratio NH₃/NO_x by a predetermined amount.

5. A method as claimed in Claim 4, comprising the further step of:

comparing the NO_x conversion after an increase in injected reductant with the NO_x conver-

sion before an increase in injected reductant and further increasing the injected reductant only if the NO_x conversion after an increase in injected reductant is greater than the NO_x conversion before an increase in injected reductant. injected reductant is greater than the NO_x conversion before an increase in injected reductant.

fraction and level.

6. A method as claimed in Claim 5, wherein further increases in the injected reductant are permitted only if the post-catalyst ammonia concentration is less than an allowable level and the ammonia slip fraction is less than an allowable fraction and otherwise the amount of injected reductant is reduced by said predetermined amount until the ammonia concentration is below the allowable fraction and level.
7. The article of manufacture comprising:
a computer storage medium having a computer program encoded therein for controlling a reductant injection upstream of a catalyst coupled to an internal combustion engine, said computer storage medium comprising:
code for increasing the amount of reductant injected if the post-catalyst ammonia concentration is less than an allowable level and the ammonia slip fraction is less than an allowable fraction, and
code for decreasing the amount of reductant injected until the ammonia concentration is below the allowable fraction and level.
8. The article as claimed in Claim 7, wherein the amount of the increase or decrease of injected reductant is sufficient to respectively increase or decrease the ratio NH_3/NO_x by a predetermined amount.
9. The article as claimed in Claim 8, further comprising:
code for comparing the NO_x conversion after an increase in injected reductant with the NO_x conversion before an increase in injected reductant and further increasing the injected reductant only if the NO_x conversion after an increase in injected reductant is greater than the NO_x conversion before an increase in injected reductant.
10. The article as claimed in Claim 9, further comprising:
code for permitting further increases in the injected reductant only if the post-catalyst ammonia concentration is less than an allowable level and the ammonia slip fraction is less than an allowable fraction and for otherwise reducing the amount of injected reductant by said predetermined amount until the ammonia concentration is below the allowable

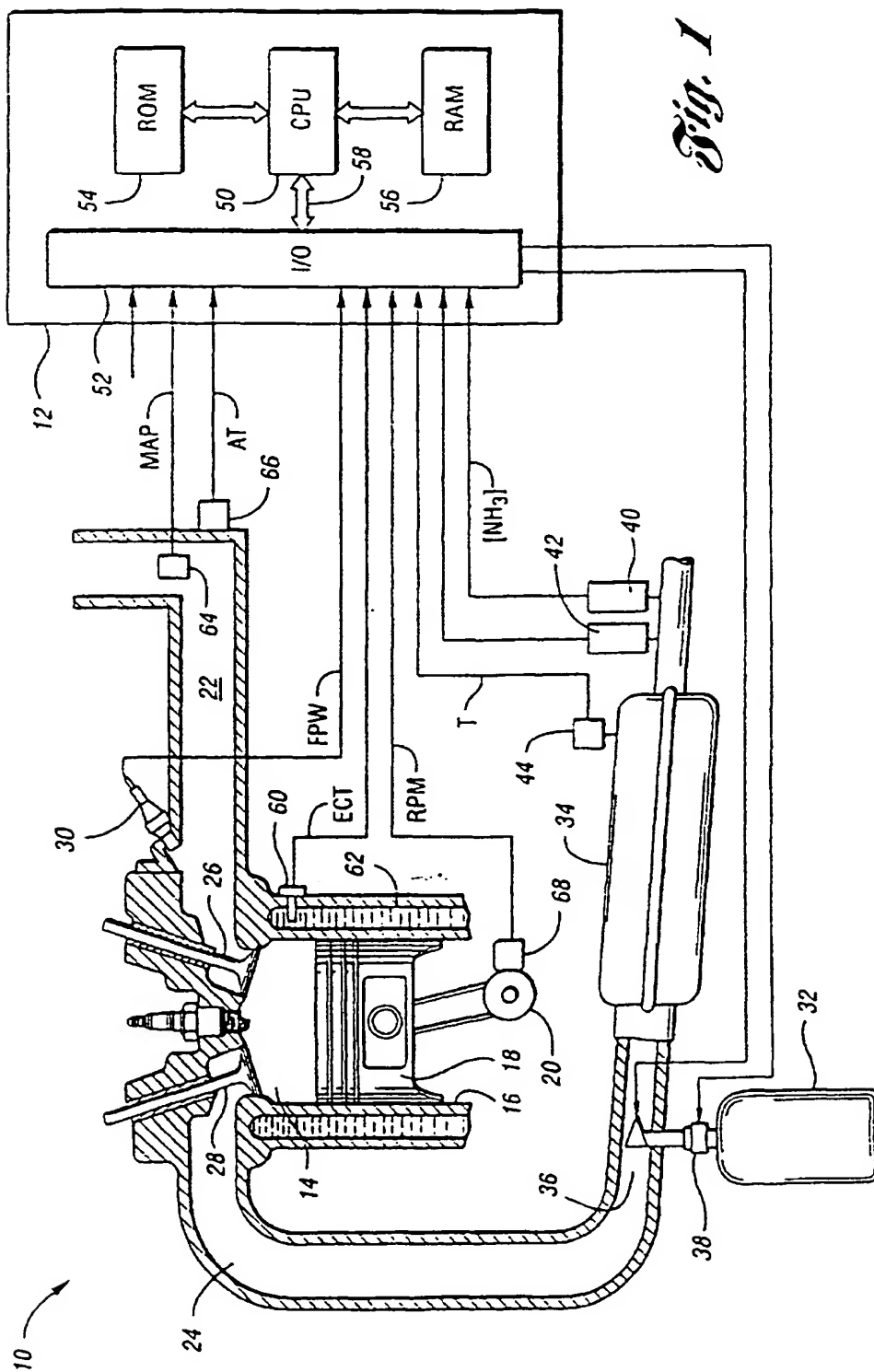
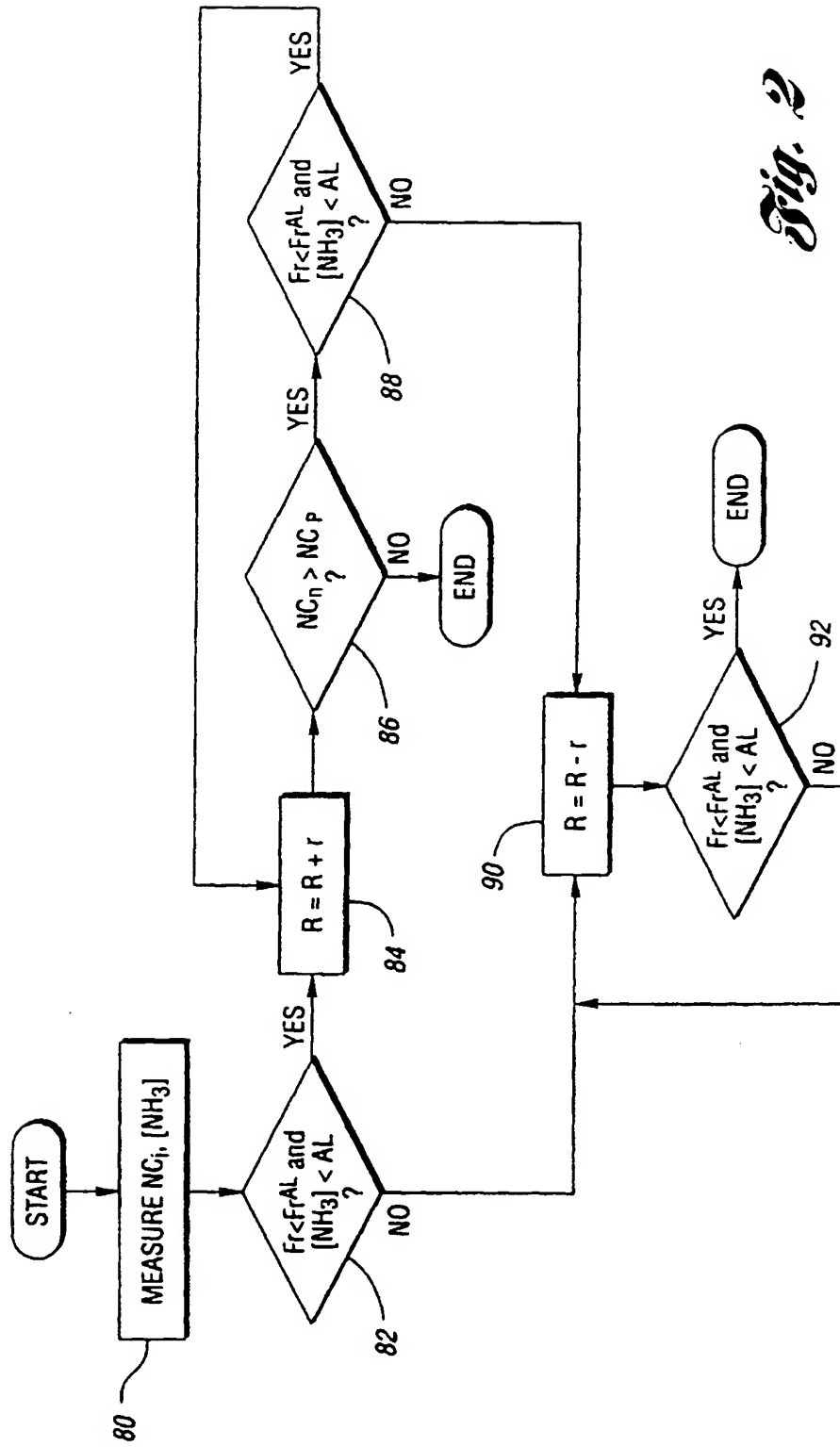


Fig. 1

*Fig. 2*

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